EEU44C04 / CS4031 / CS7NS3 / EEP55C27
Next Generation Networks

Self Organizing Networks

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System Complexity

"Science has explored the microcosms and the macrocosms: we have a good sense of the lay of the land. The great unexplored frontier is complexity"

(Heinz R. Pagels, The Dreams of Reason, 1988)

Characteristics of Complex Adaptive Systems

1. Non-linearity
This construct means that small actions can stimulate large reactions (otherwise known as the butterfly effect) in which highly improbable, unpredictable and unexpected events have huge impacts.

2. Emergence
The appearance of patterns occurs due to the collective behavior. What emerges cannot be planned or intended. The whole of the interactions becomes greater than the sum of the separate parts.

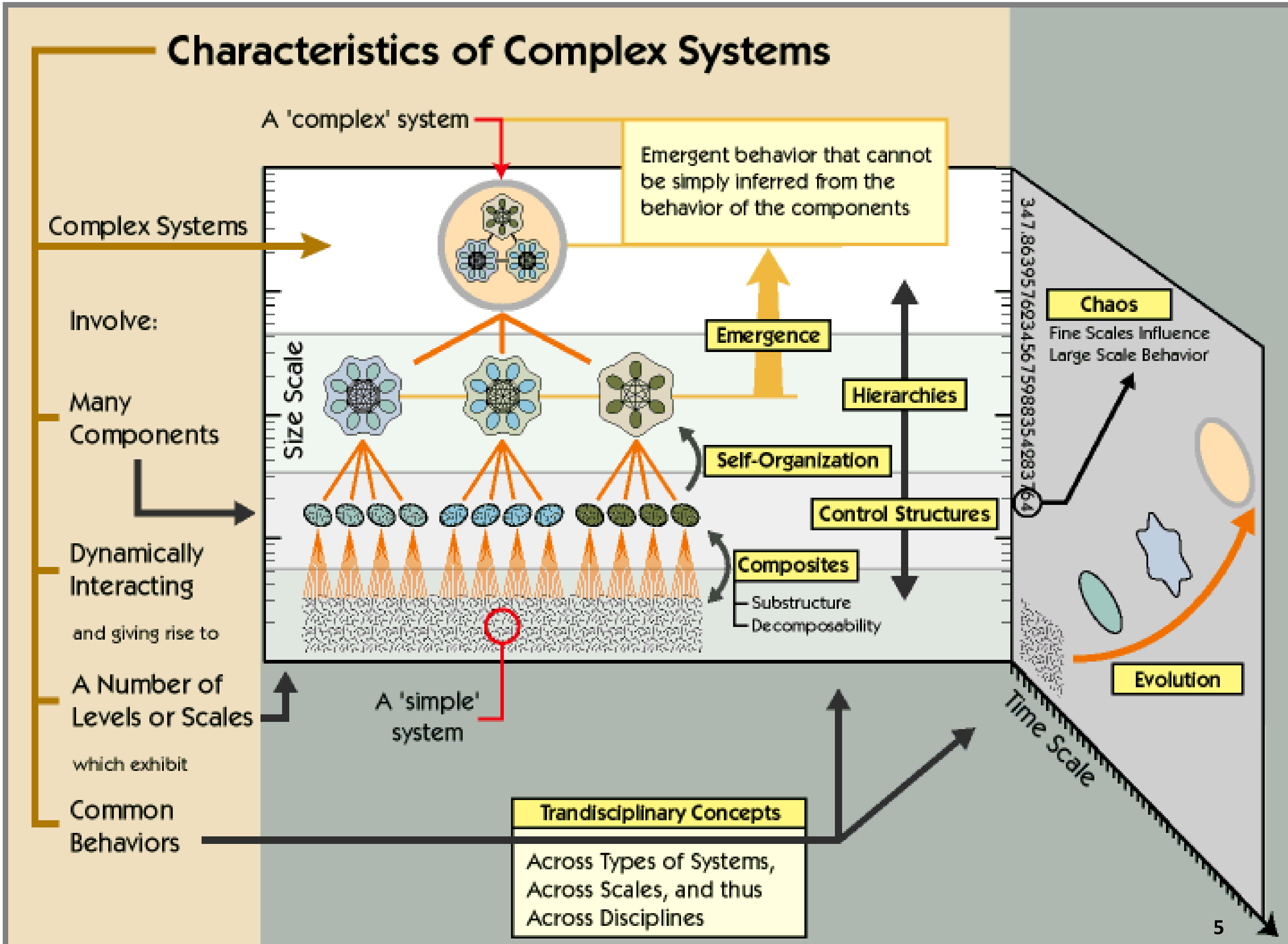
3. Dynamical systems change
Interactions within, between and among subsystems and parts are volatile, turbulent, and cascade rapidly and unpredictably.

Characteristics of Complex Adaptive Systems

4. Adaptation
Interacting elements respond and adapt to each other so that what emerges and evolves is a function of ongoing adaptation, among both interacting elements and the elements and their environment.

5. Uncertainty
Processes and outcomes are unpredictable, uncontrollable and unknowable in advance. There is no clear idea what might happen or how likely possible outcomes are.

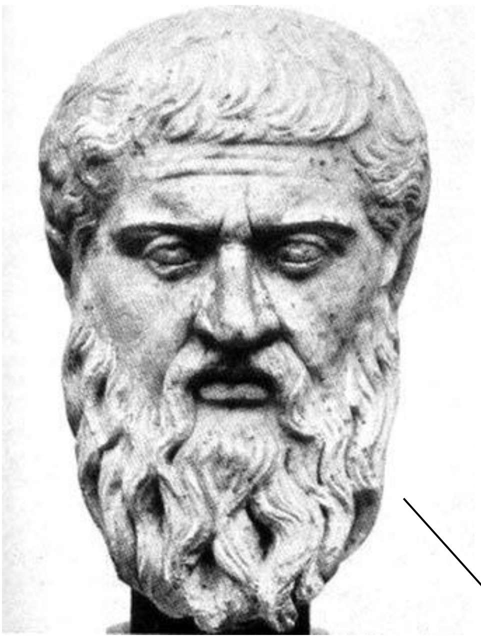
6. Co-evolutionary
As interacting and adaptive agents self organize, ongoing connections emerge that become co-evolutionary as the agents evolve together (co-evolve) within and as part of the whole system over time.



Characteristics of Complex Systems
A 'complex' system
Emergent behavior that cannot be simply inferred from the behavior of the components
Complex Systems
Involve:
Many Components
Dynamically Interacting
and giving rise to
A Number of Levels or Scales
which exhibit
Common Behaviors
Size Scale
Emergence
Hierarchies
Self-Organization
Control Structures
Composites
Substructure
Decomposability
347.86395762345675988354283764
Chaos
Fine Scales Influence Large Scale Behavior
Evolution
Time Scale
A 'simple' system
Trandisciplinary Concepts
Across Types of Systems, Across Scales, and thus Across Disciplines

Emergence: the holy grail of complex systems

How macroscopic behavior arises from microscopic behavior.

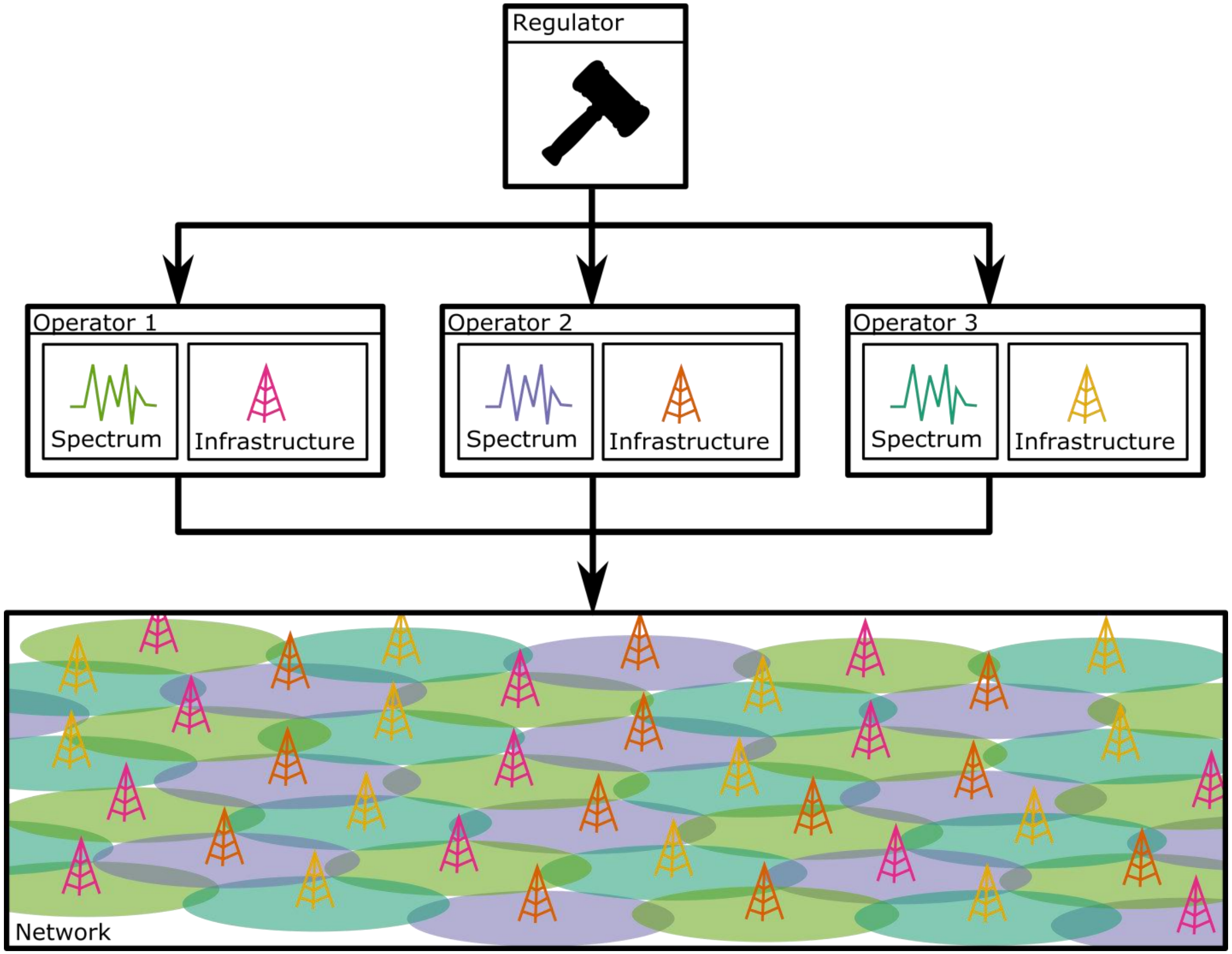


Plato

Emergent entities (properties or substances) ‘arise’ out of more fundamental entities and yet are ‘novel’ or ‘irreducible’ with respect to them.
Stanford Encyclopedia of Philosophy
http://plato.stanford.edu/entries/properties-emergent/

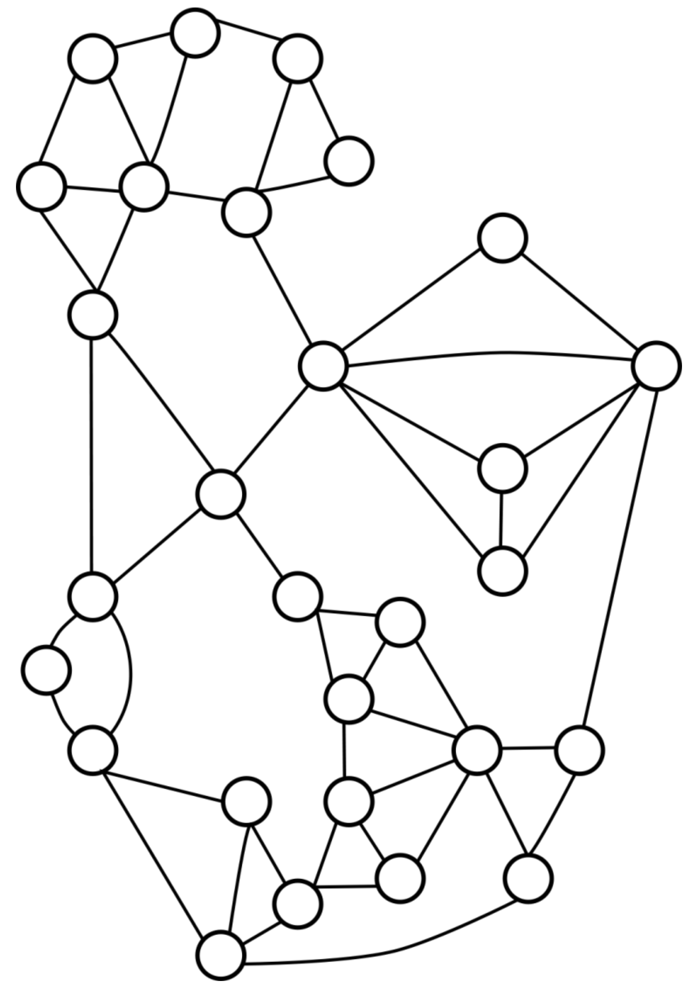
Warning: philosophy ahead.

Networks are Complicated



Understanding Interactions

- Networks are built of interactions
  - Handshaking/device association
  - Collection of links
- Structure of interactions has impact
  - MAC protocols
  - Collected/cascaded
- Need way of modelling interactions



Methods for Modelling

- Cellular Automata (CA)
  - Spatial lattice of cells
  - States
- Agent Based Modelling (ABM)
  - Simplified entities within system interacting w/ each other
  - Signals and Rules
- Others are out there

CA - Basic Concepts

- Spatial lattice of cells with states
- Not necessarily physical space
- Cell state at time *t+1* depends on cell state at time *t* and state of some of neighbours at time *t*
- Updates follow simple rules (typically uniform for all cells)
- Useful for examining situations with some inherent structure
- Subject of great mathematical study

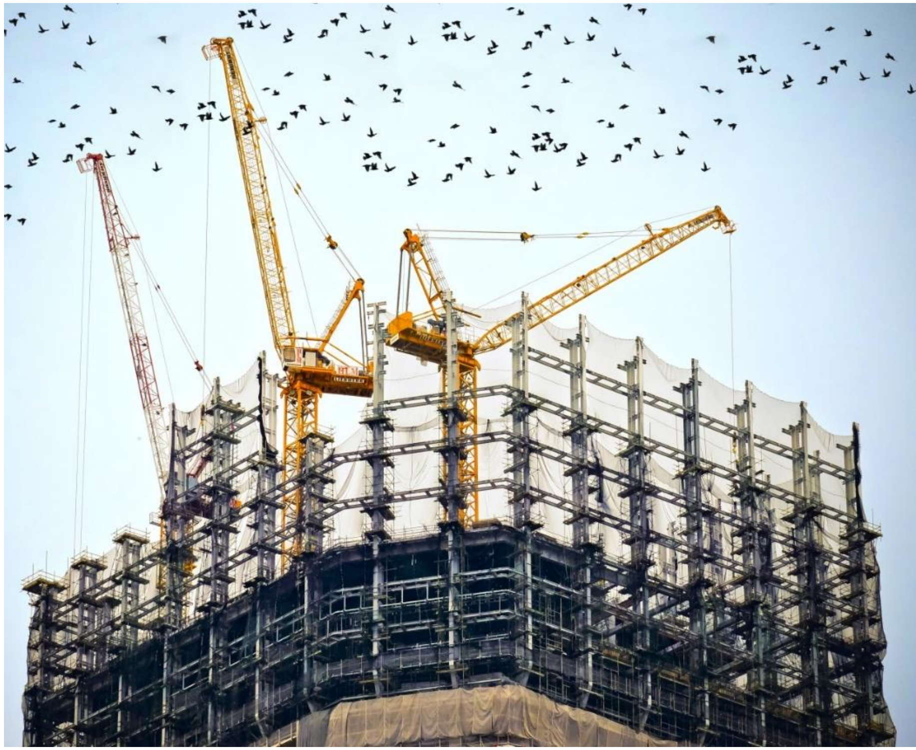
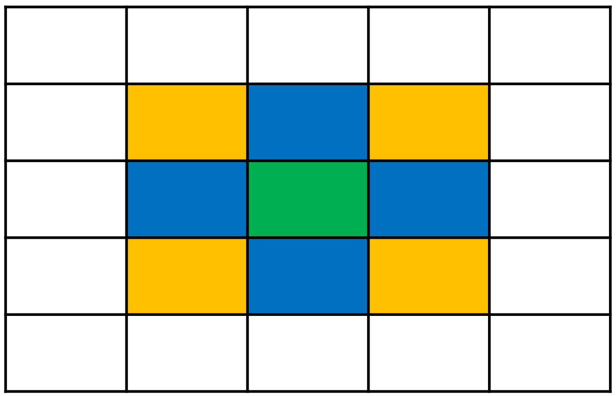


Photo credit: Danist Soh
https://unsplash.com/danist07/portfolio

Much of the material here on CA is adapted from the work of Professor David Wolfe Corne at Heriot Watt University
http://www.macs.hw.ac.uk/~dwcorne/Teaching/

CA - Neighbourhood



- Neighbourhood defines influence
  - State depends on neighbours
- Various Possibilities
  - Green – Target node
  - Blue – von Neumann neighbourhood
  - Blue + Orange – Moore neighbourhood
  - Entire table – Extended Moore neighbourhood

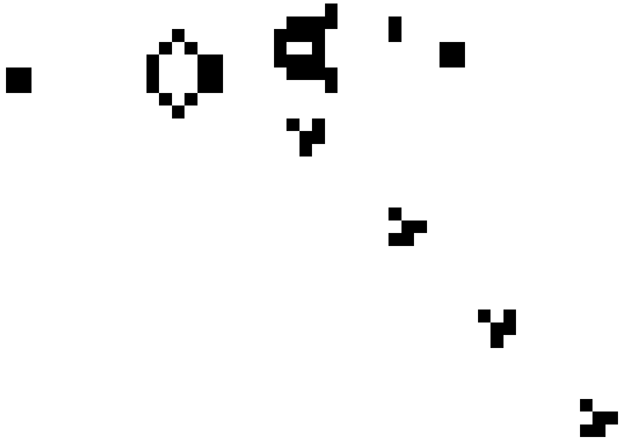
CA - End Conditions

- The final state depends on the neighbourhood and update rules
  - A CA is defined by the way interactions are structured
  - Various options emerge from the structure of interactions
- Possibilities:

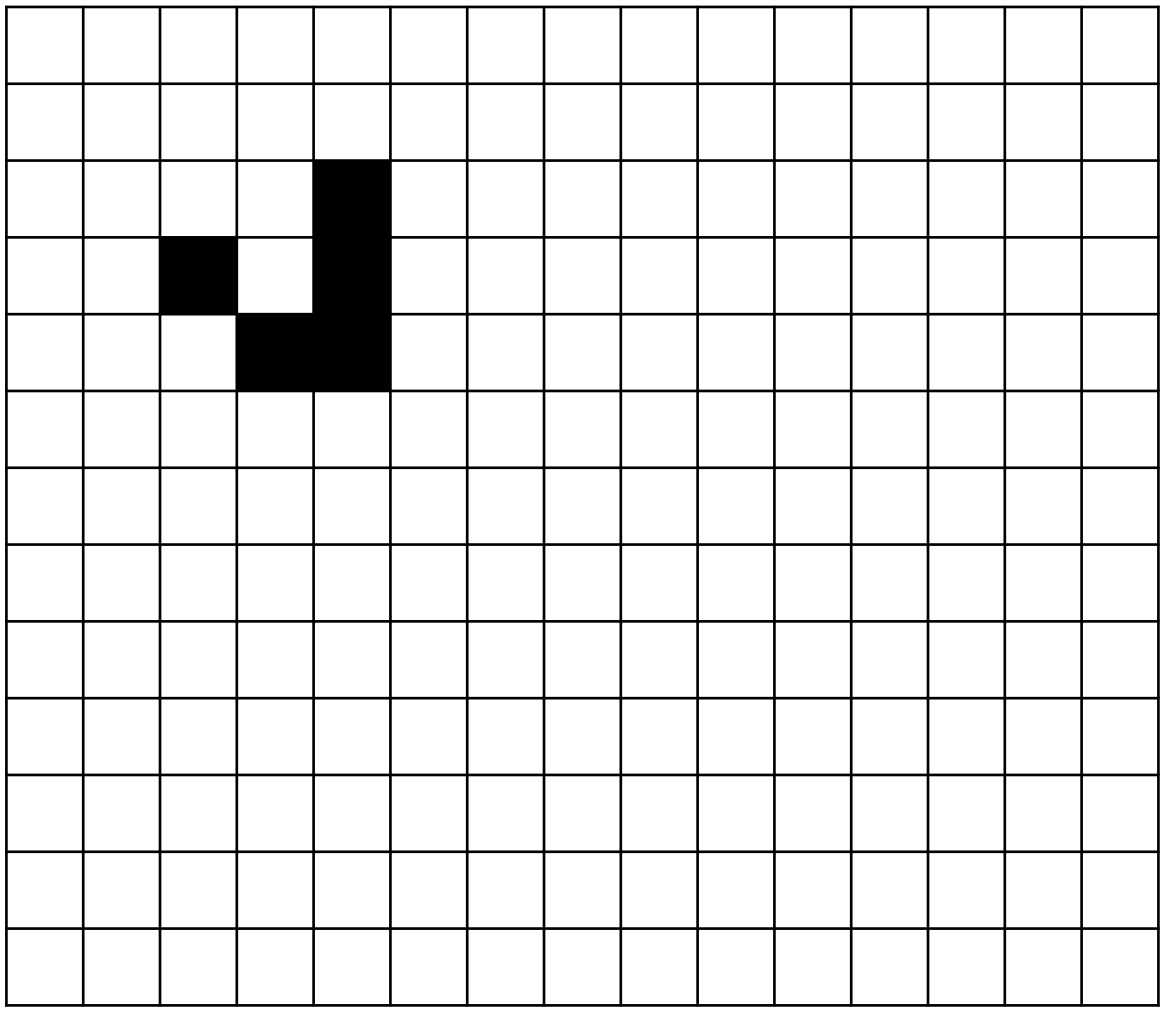
1. CA achieves unique state from any starting condition
2. Repeating patterns emerge
3. Aperiodic-chaotic patterns with consistent statistical properties
4. CA dies out

John Conway’s Game of Life

- 1970 – Simulation of Life
  - John Horton Conway
  - Zero Player Game
  - Moore Neighbourhood
- Rules
  - Any live cell with fewer than two live neighbour dies
  - Any live cell with two or three live neighbours lives
  - Any live cell with more than three live neighbours dies
  - Any dead cell with exactly three live neighbours becomes a live cell



Game of Life - Glider



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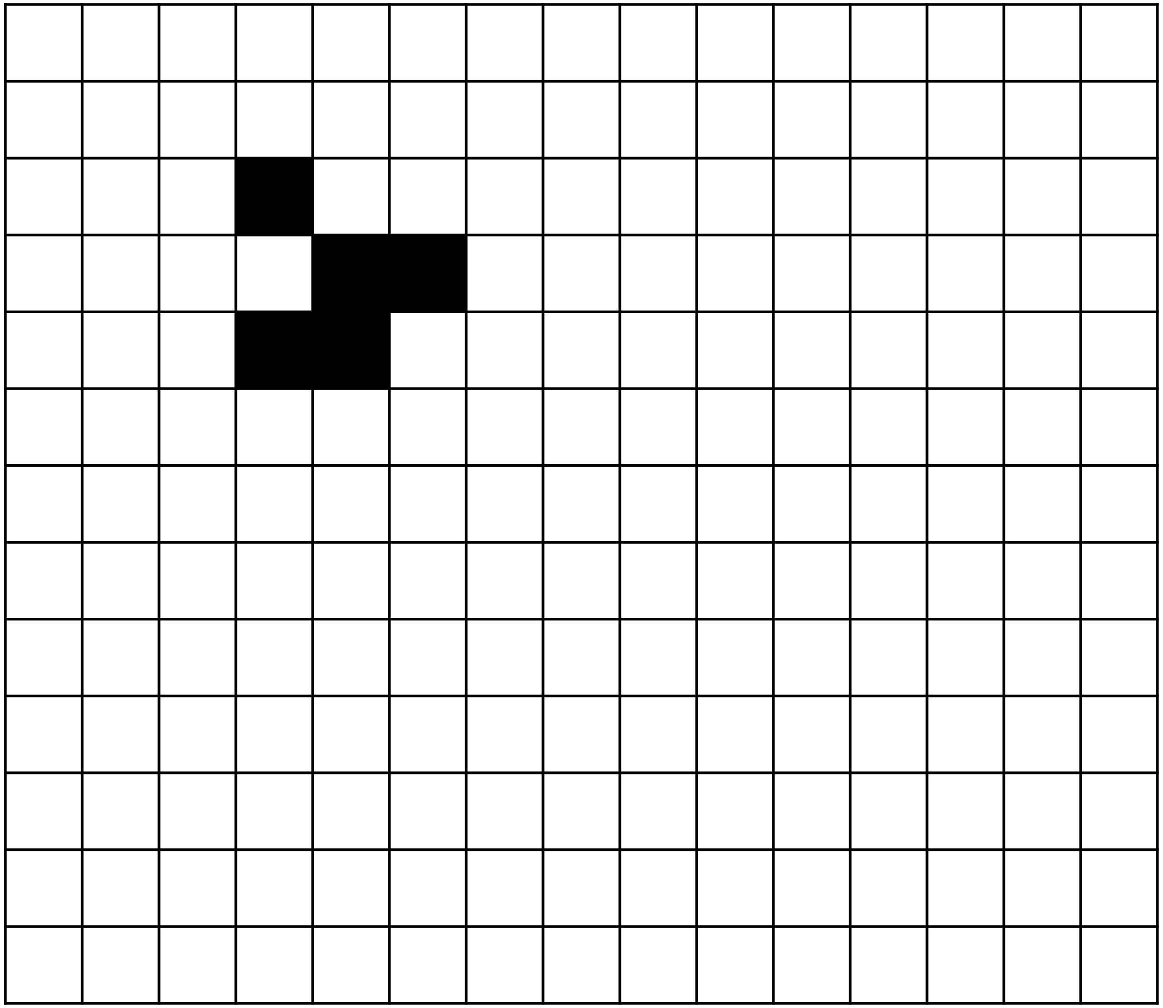

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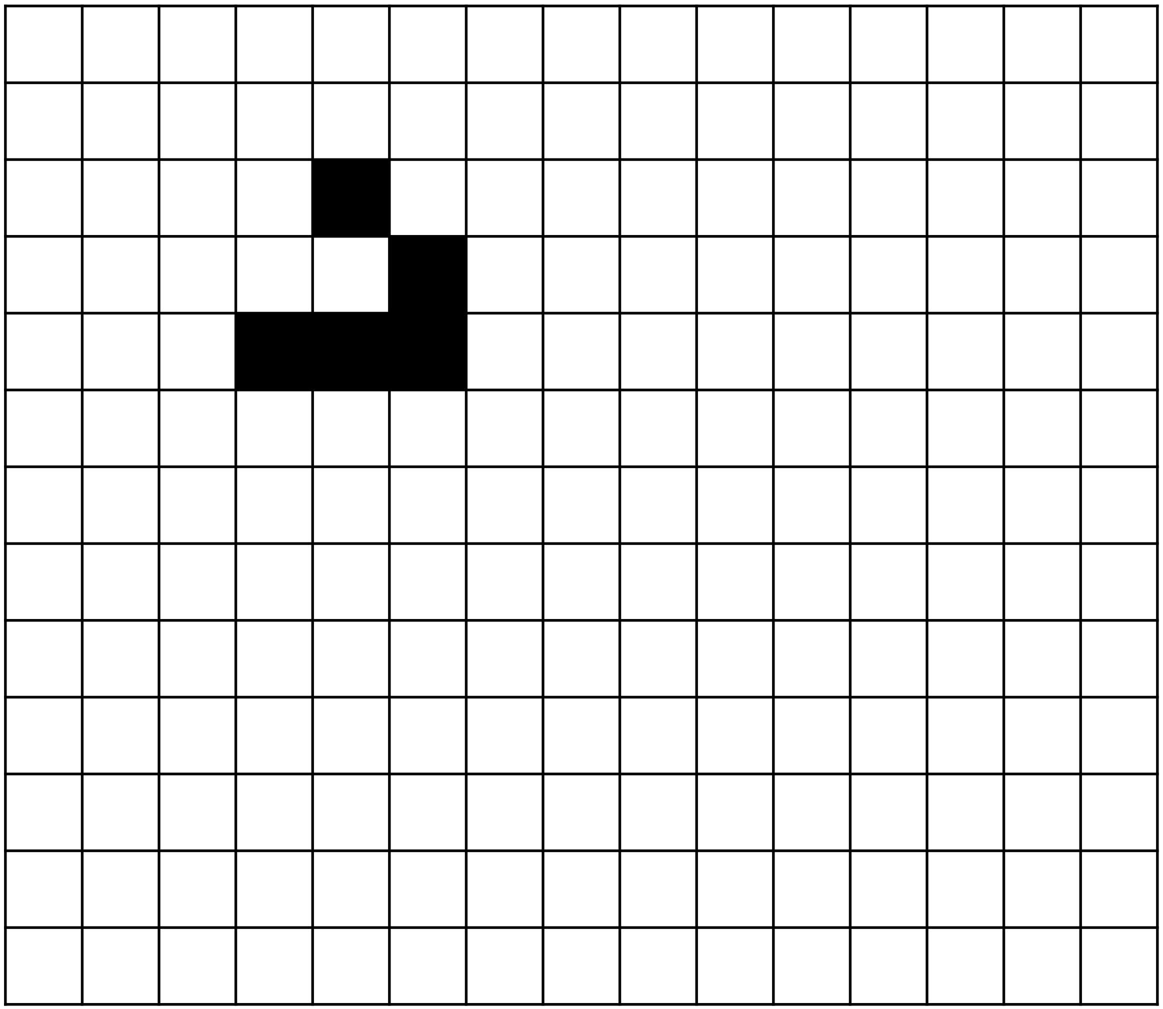

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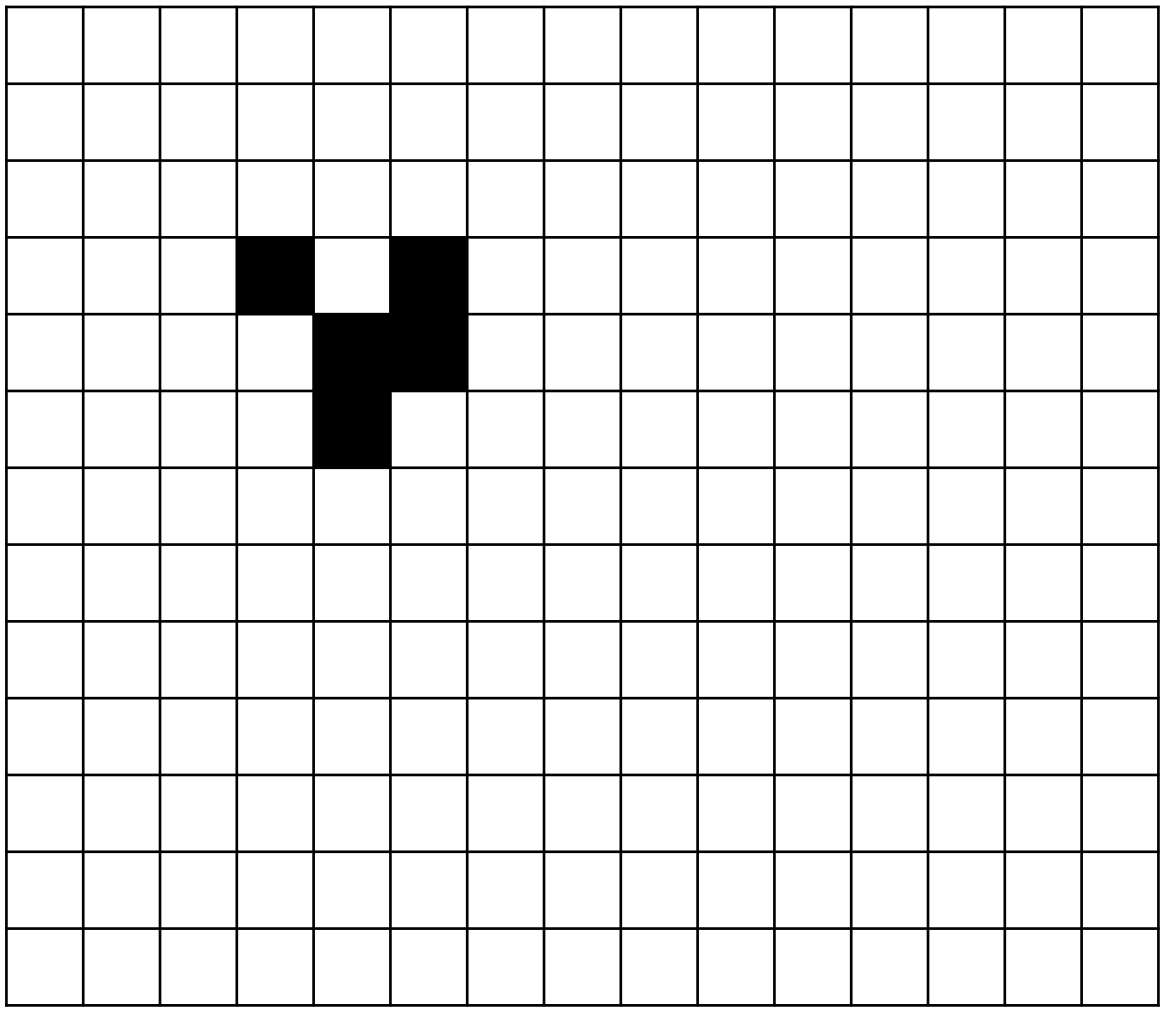

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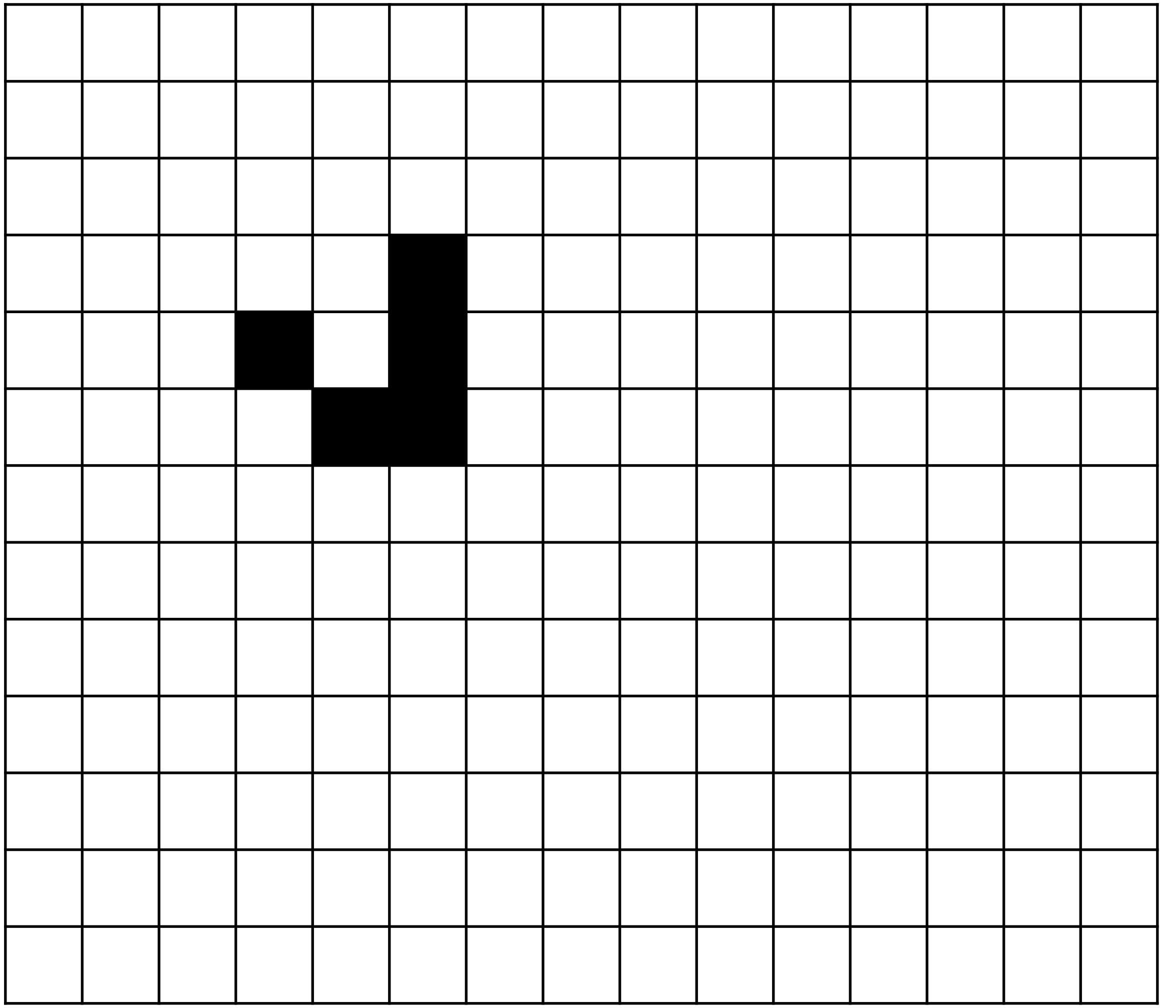
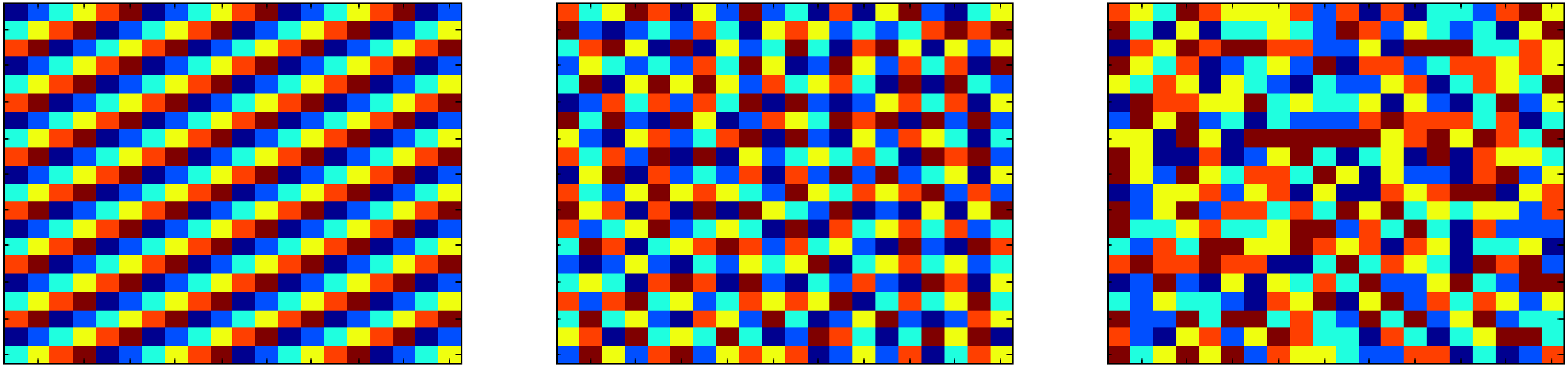


Cellular Communications

- CA permits a novel examination of telecom
  - Cells might be communications cells
  - Updates can attempt to avoid interference



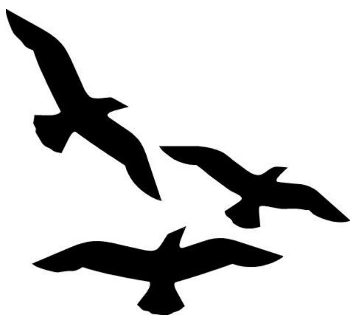
(a) (b) (c)

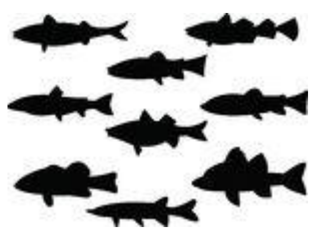
I. Macaluso, H. Cornean, N. Marchetti, and L. Doyle, "Complex communication systems achieving interference-free frequency allocation," in *IEEE ICC*, 2014, pp. 1447–1452.

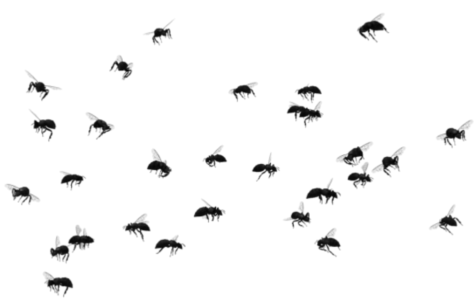
Agent Based Modelling

Photo Credit: Barn Images
https://unsplash.com/photos/QdiFXri4Doo

ABM - Basic Concepts





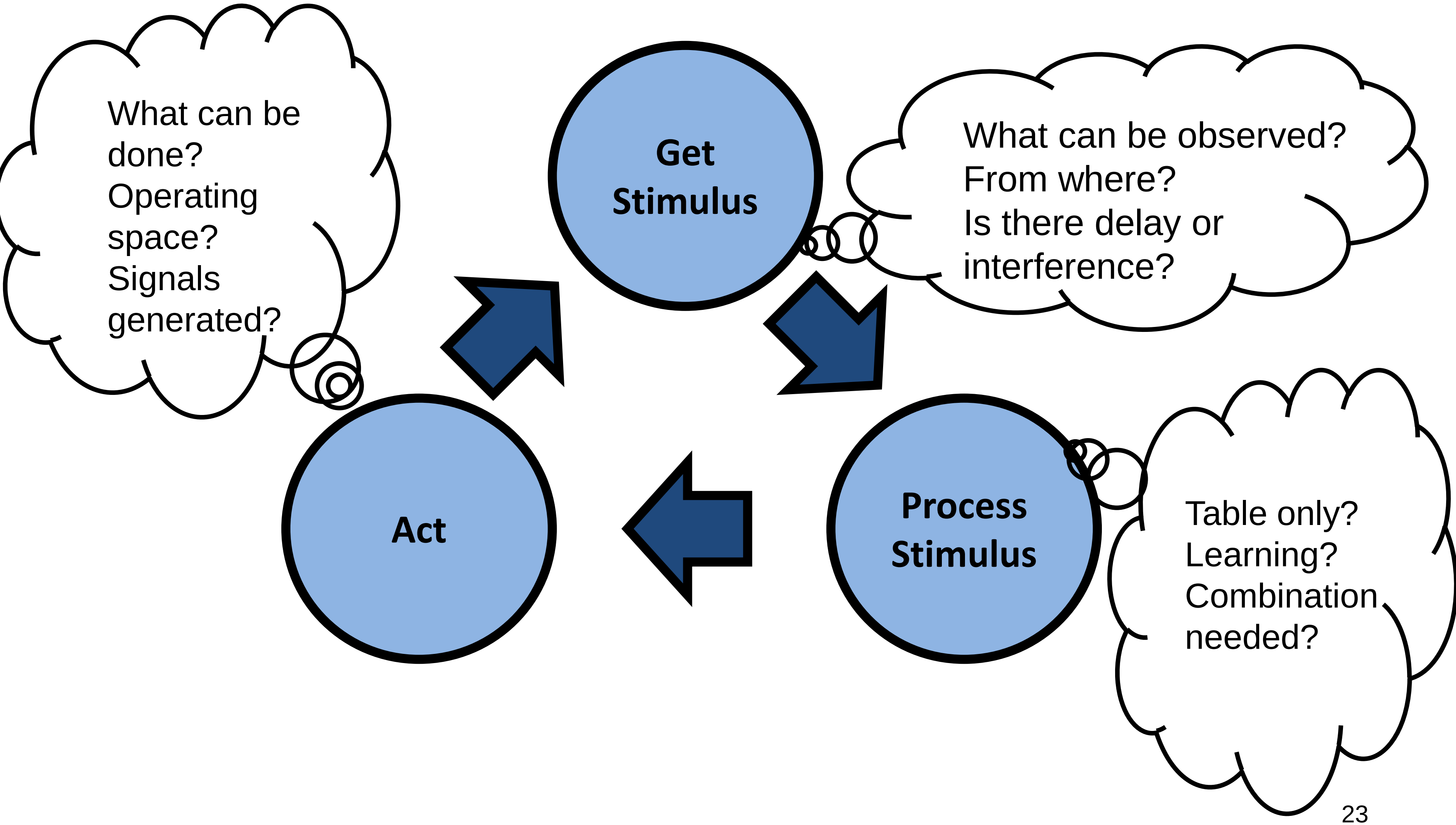


- Agents
  - Anything that makes choices in a network
  - Autonomous (own goals, own behaviours)
  - Can be adaptive
  - Can exist on multiple levels
- Assumptions
  - Agents operate in parallel
  - No central command
- Examples
  - Birds, fish, bees

ABM - Rules

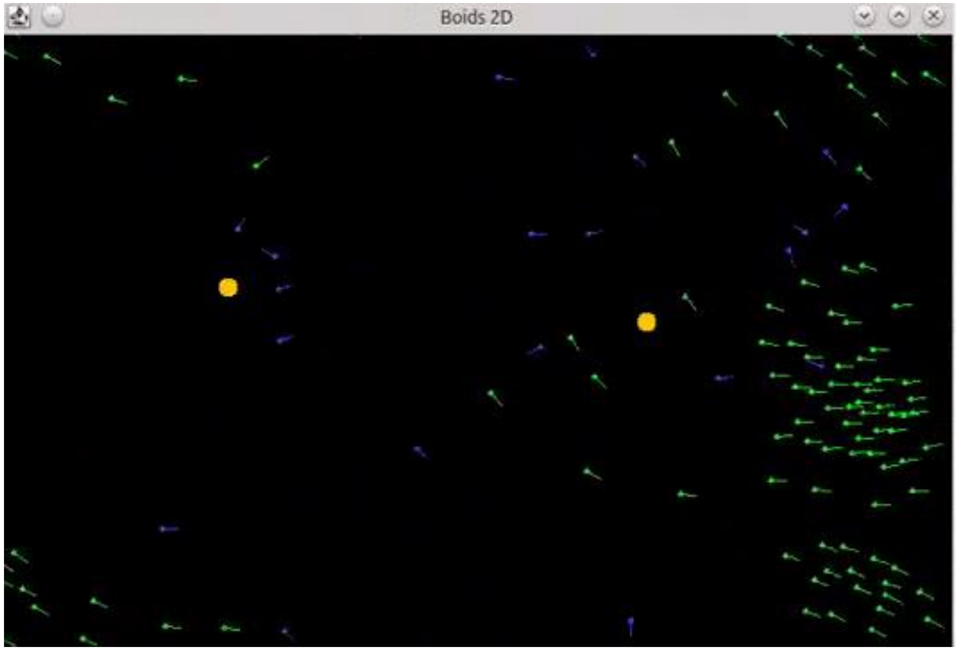
- Agents are guided by internal rules
  - Akin to cognitive engine
  - Typically, tables with condition and action but not always
  - Simple
- Combination of rules leads to emergence
  - Sum of individuals does not explain completely collective action
    - Wetness of water
    - Nonlinear combinations

ABM - Agent Cycle



Boids

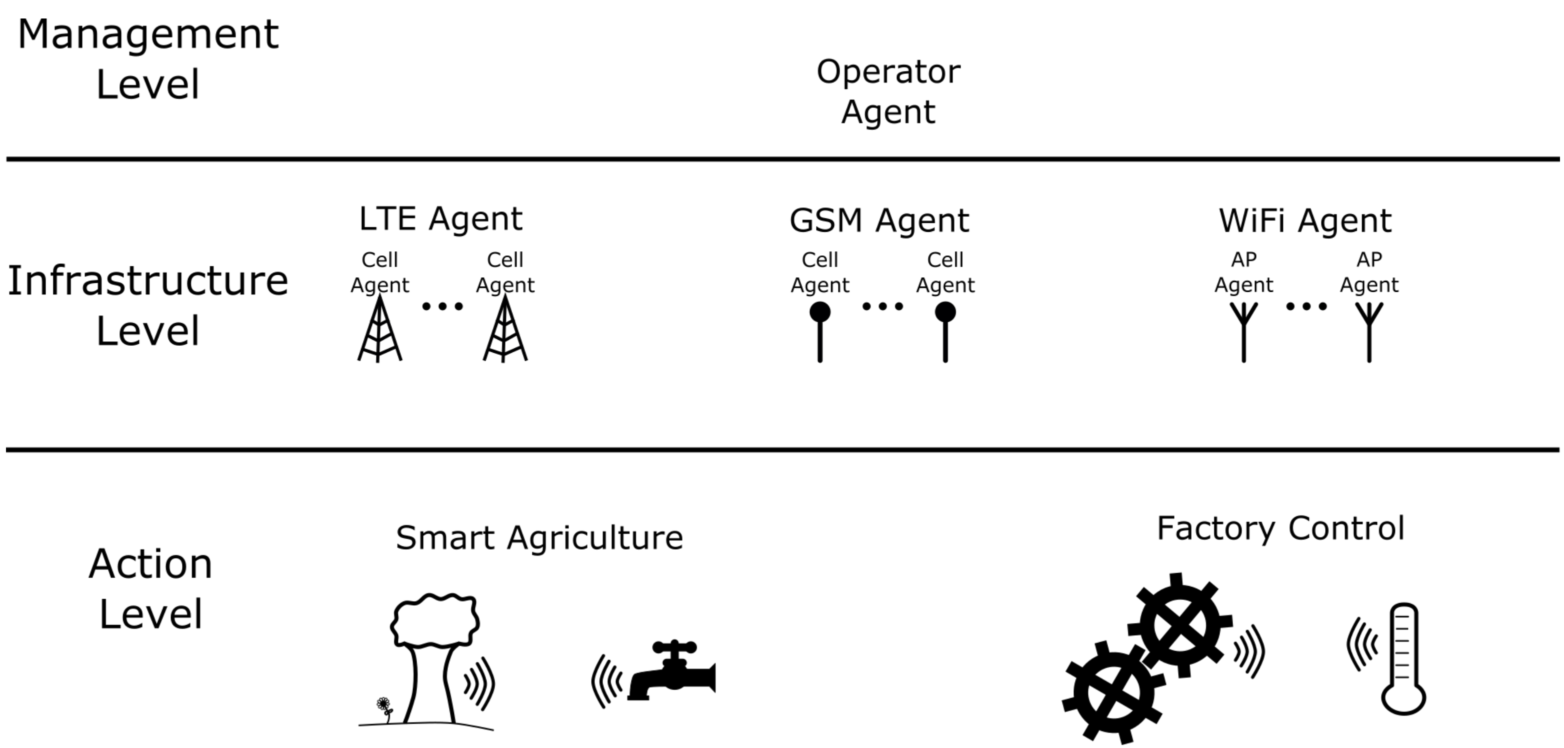
- 1986; Flocking of Birds
  - Craig Reynolds
  - Paper in 1987 ACM SIGGRAPH
  - Single level model
- Rules
  - Separation
  - Alignment
  - Cohesion



Telecommunications ABM

- Agents as network entities
  - End devices (phones), base stations, core units
  - Can examine overhead necessary for coordination
- Allows integration of non-telecoms elements
  - Physical events → e.g. varying probabilities of road traffic generation
  - Management systems
- Captures emergence from collection of rules
  - How do management systems handle various events

Full System Modelling



Which among the following statements is false when speaking about an ABM agent?

- ❑ An ABM agent is anything that makes choices in a network
- ❑ An ABM agent might need a central command to operate in large networks
- ❑ An ABM agent has its own goals and behaviors
- ❑ An ABM agent operate in parallel with other ABM agents

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Acknowledgments

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- Dr Irene Macaluso, CableLabs, USA

References

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